A Behavior of Unsteady Cavity on a Wing Section

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Abstract

In order to simulate the cloud cavitation on hydraulic machinery, the unsteady cavitation on a rectangular wing section was observed in the cavitation channel of the Miyakonojo National College of Technology. The attack angle was forced to change from 10deg. to –10deg. by a strike of hammer. As the attack angle decreased, the sheet cavitation left the leading edge of wing and changed into cloud cavities on the mid-chord of wing.

1. Introduction

The unsteady cavity on the rotating blades of hydraulic machinery makes troubles such as erosion, vibration, noise and reduction of performance(For example,Brennen 1995). When the unsteady cavity collapses, the very high pulse of pressure is emitted to the blade surface and to the surrounding liquid, causing such troubles. In this case the cavity leaves the leading edge of blade, collapses as a whole on the blade and becomes a cloud of small bubbles as reported by Chiba(1975).
The unsteadiness of cavity comes from the cyclic change of direction of flow to the rotating blade due to the non-uniformity of flow field. Therefore the pressure around the blade which may control the behavior of unsteady cavity belongs to the gust problem. To solve the problem, the scale model tests are usually carried out in the simulated flow field in the cavitation tunnel to confirm that the designed blade will be free from such troubles. These results can be accumulated as a data base for good design of hydraulic machinery. But more detailed characteristics of unsteady cavity should be made clear to give the design tool to avoid initially the cavitation troubles. Under what condition does the unsteady cavity leave the leading edge of blade ? How does the whole sheet cavity collapse at a time into a large amount of small cavities and give an accumulation of small pits on the blade material ? In this respect, various kinds of experiments to simulate the unsteady cavity and theoretical analyses about them will be necessary.
In this study, as one of the simulation methods of cloud cavity, the unsteady cavity on the wing section was observed when the attack angle was suddenly changed. At first the attack angle of blade was so set as to give a sheet cavity as long as its chord. Then the attack angle was forced to change into the opposite side by a strike of hammer. Under a certain condition, cloud cavity was successfully simulated on the blade.

2. Test Method

The cavitation channel of the Miyakonojo National College of Technology was used in this study. Its general arrangement is shown in Figure 1. The water came down from the reservoir tank on the roof and flew into the vacuum tank in the room. In the midway, the transparent pipe of 40 mm in diameter was set horizontally. This pipe was the test section. The static pressure and velocity in the test section were controlled by the pressure in the vacuum tank and the valve situated on the downstream of the test section.

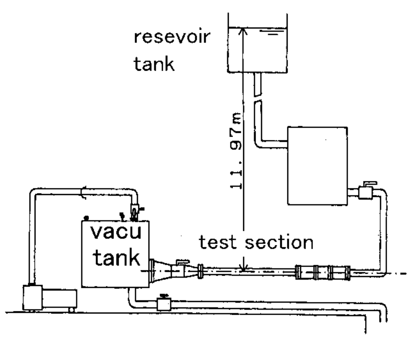


Figure 1 Cavitation Channel

The tested wing had 40 mm chord length and 35 mm span. The section shape was ogival with the thickness of 8.97 mm. The radii at leading and trailing edges were both 0.5 mm. The wing was set vertically in the channel by the vertical shaft fastened at the 1/3 chord from the leading edge. The shaft penetrated the bottom of the test section and was supported there. Outside of the test section, a horizontal lever was fastened to the shaft. A hammer of 1.1 kg mass was so equipped as to swing down from the preset height to strike the free end of lever. Thus the wing was rotated by the lever with the rotational speed given by the hammer speed.

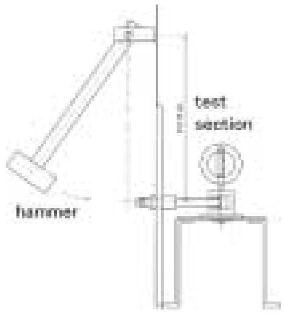


Figure 2 Test Apparatus

The unsteady behavior of cavity on the wing was photographed by the strobo light flashed at the preset time after the contact of hammer. This process was realized with the combination of a multipulser and signal generator.

3. Experiments

The procedure was as follows. The wing was set in the test section at the attack angle of 10 degree. The pressure in the vacuum tank was reduced to 450 mmHg by the vacuum pump. The hammer was supported at the preset height. Then the control valve was opened to let the water flow through the test section. At this condition the length of sheet cavity developed on the suction side of the wing became as long as the chord length. The hammer was released and swung down. The attack angle changed from 10 degree to –10 degree with the rotational speed determined by the hammer speed. Three kinds of hammer heights were applied, namely 73.2, 250 and 426.8 mm. The resulting rates of change of attack angle are as follows.

Hammer height	Rate of change of attack angle
73.2 mm	59.8 rad./s
250.0 mm	110.5 rad./s
426.8 mm	144.4 rad./s

The timing of flash was so selected that the instantaneous cavity was recorded at every 2 degree of attack angle from 10 degree to –10 degree.

4. Results

The photos of cavities are shown in the followings
.
(1) hammer height=73.2mm are shown in Figure 3.
The cavity at 10 degree was fully developed. As the attack angle decreased the cavity began to shrink.
At 0 degree, the rear part of cavity was going to collapse, while the fore part looked like a shrinking sheet cavity.
At –6degree, the rear part collapsed as a whole and became cloud cavity. This cloud cavity resembled that on the blade of pumps. In this case a half volume of the initial sheet cavity were concerned with the energy of cavity collapse. The fore part disappeared toward the leading edge of the wing.

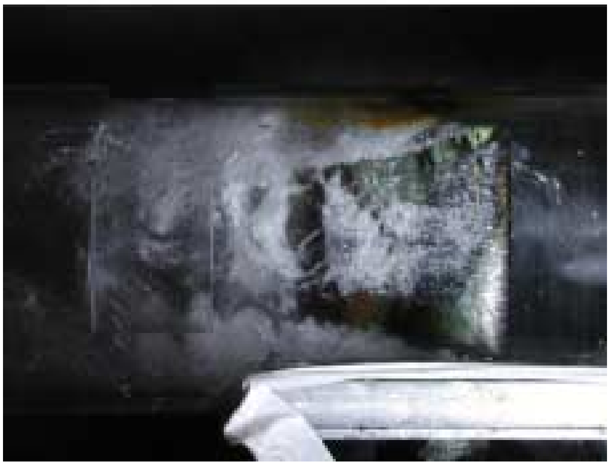
(2) hammer height =250 mm is shown in Figure 4
The cavity at 8 degree splittted into the rear part and fore part. At 4 degree, the rear part collapsed. The fore part became the narrow sheet cavity parallel to the leading edge of the wing. This sheet cavity situated at some distance from the leading edge of the wing. The unsteady cavity left the leading edge of the wing, as is often the

Attack angle = 10 deg

Attack angle = 0 deg

Attack angle = –6 deg.

Figure 3 Cavities at Hammer Height =73.2 mm



Attack angle = 8 deg

Attack angle = 4 deg

Attack angle = 0 deg.

Figure 4 Cavities at Hammer Height =250 mm

Attack angle = 10 deg

Attack angle = 0 deg

Attack angle = –2 deg.

Figure 5 Cavities at Hammer Height =426.8 mm case on the blade of hydraulic machinery. At 0 degree, the rear part rebounded and became cloud cavity. The fore part collapsed near the same position on the wing at 4 degree. The whole potential of the initial sheet cavity was converted into the two collapses of cavities.

(3) hammer height =426.8 mm

The behavior of the unsteady cavity relatively similar to that at hammer height = 250 mm.
But the fore part carried the larger part of the initial cavity. Therefore the collapse of the fore part seemed to be dominant.

5. Considerations

In the above experiments, the collapse of cavity was observed. The cloud cavities in the photographs resembles those observed on the blades of hydraulic machinery.
The initial sheet cavity left the leading edge of the wing in the two cases, hammer heights= 250 and 426.8 mm. The narrow sheet cavity, which was the fore part of the split initial sheet cavity, shrunk as follows. The downstream edge of narrow sheet cavity moved towards upstream with a certain speed .
This speed was thought to be related to that of shrinking speed of the bubble with diameter equal to the length of the sheet cavity(Chiba,1999). The upstream edge left the leading edge of the wing before the downstream edge reached there. Then both edges met and collapsed at the midway on the wing. The collapsing procedure after leaving the leading edge of the wing seemed similar to that of the collapsing bubble explained by Lord Rayleigh(1917). This suggested that the change of attack angle should have enough speed to leave the leading edge of the wing. Considering that the leaving did not occur at hammer height =73.2 mm, there would be the limiting condition between hammer height =73.2 mm and 250 mm.
. In this experiment, the cavity was steady before the strike of hammer. Therefore the after part of split initial cavity was a mass of small bubbles, which is often seen at the rear end of steady sheet cavity. The mass of bubbles collapsed as a whole and became cloud cavity near the trailing edge of the wing.
The collapses occurred at two positions on the wing in this experiment. It seems that the collapse of fore part is severer, according to the experience on the pitching wing by Chiba (1975).

6. Conclusion

The unsteady cavity on the rectangular wing was obseved when its attack angle was suddenly decreased by a strike of hammer. The initial sheet cavity split into two parts, fore part and after part. The fore part left the leading edge of the wing and collapsed at a midway on the wing. It was suggested that there was a limiting value of changing speed to make the cavity leave the leading edge of the wing. The rear part also collapsed. Therefore, the reproduction of cloud cavity was successfully attained by this method. This will serve a base to proceed the understanding of phenomena of cloud cavitation

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